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RAINY HOLLOW CONTAMINANT TRANSPORT MODELING

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1.0 Executive Summary

At the Rainy Hollow site, detailed investigations have been carried out to determine the current contaminant loading into the biosphere. The original focus of the investigative studies was to determine if concentrations at the outflow face (Klehini River) are likely to increase with time. In order to deal with this issue an appropriate model of the contaminant movement needed to be developed. This report expands on the conceptual model of the DDT transport at the Rainy Hollow site previously developed (RRU, 1997) and evaluates the validity of that model with a mathematical solution to the appropriate boundary value problem. The additional analyses and documentation are intended to provide reviewers with more details on the proposed model and evaluate the likely accuracy of predictions of DDT fluxes to the Klehini River.

The modeling and monitoring strategy proposed herein is designed to answer several key questions. One of these questions to be answered after five years or sooner is whether the predictions can confirm that no further action is required, and that the monitoring program can be discontinued. If the converse is true then additional contaminant risk assessment may be needed to determine whether more pro-active remediation is warranted.

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2.0 Overall Motivations of Contamination Modeling

2.1 Background

There are essentially four fundamental questions that need to be addressed in any groundwater contaminant assessment. These questions are:

- **Where** will the contaminants re-enter the biosphere?
- **When** will the contaminants re-enter the biosphere?
- **What** will the concentration of these contaminants be at the exit points?
- **What** is the risk to the public, aquatic wildlife, etc.?

The answer to these questions for many contamination assessment or remediation studies lies in the understanding of the groundwater flow system. This system plays a dominant role in either transporting or mitigating the effects of contaminants.

The question of *what* will be the exit concentrations revolves around understanding and detailing which particular aspects of the source represent a hazard and also detailing what specific components are present. Such aspects of the source include concentrations, decay/production rates, mobilities and other geochemical properties. To answer these questions one must understand various chemical interactions that are likely to take place.

The question of *where* the contaminants re-enter the biosphere involves investigating the hydrogeology of the site. In this case the natural environment and groundwater flow directions must be understood.

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When the contaminants arrive at the biosphere depends on both the groundwater velocities and dispersion effects that cause mass to move mechanically along directions specified above. One must pay close attention to those effects such as sorption which cause material to move slower than prevailing groundwater. In addition, chemical effects such as radioactive decay, biodegradation, etc. reduce mass as it moves.

With respect to the Rainy Hollow site, the *where* and *when* questions as posed above are answered, however the *what* concentration question needs to be answered. The original focus of the investigative studies was to determine if concentrations at the outflow face (Klehini River) are likely to increase with time. In order to deal with this issue an appropriate *conceptual model* of the site needs to be developed. Spitz and Moreno (1996) define conceptual model as "simplified representation of the investigated groundwater system for which an approximate solution is sought". *This report expands on the conceptual model of the DDT transport at the Rainy Hollow site previously developed (RRU, 1997) and evaluates the validity of that model with a mathematical solution to the appropriate boundary value problem.* The additional analyses and documentation are intended to provide reviewers with more details on the proposed model and evaluate the likely accuracy of predictions of DDT fluxes to the Klehini River.

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3.0 Contaminant Transport Modeling

3.1 Overview

The purpose of a model that simulates contaminant transport is to compute concentrations of a dissolved species in an aquifer at any specified place and time. In this way, the *when* and *what concentration* questions can be answered. To a large degree the groundwater flow system modeling controls the *where* question.

It should be noted that the contaminant transport equation is linked to the groundwater flow equation through the groundwater velocity term. Thus, precise spatial and temporal knowledge of the groundwater flow field is required. The simulation of contaminant transport has four possibilities related to the assumption of the groundwater flow and mass transport. These are:

1. Steady groundwater flow and transient (time dependent) contaminant transport.

2. Transient groundwater flow and transient contaminant transport.

3. Steady groundwater flow and steady state contaminant transport.

4. Transient groundwater flow and steady state contaminant transport.

The vast majority of modeling efforts carried out usually assume that (1) is valid; i.e. it is assumed that the groundwater flow field is steady. There are many reasons for this assumption and some of these reasons revolve around the necessary data for a combined transient analysis. The validity of the steady state assumption has not been verified for the simulations at the Rainy Hollow site.

In addition to these issues the reader should also be aware of the state of scientific knowledge with respect to mass transport modeling. As Schwartz (1990) states "Numerical solute transport models first developed about 20 years ago and the field has advanced from theory to practice within

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a short time. A great demand for numerical code to solve practical and complex field problems arose, however a large base of experience and hypothesis testing has not been accumulated. Nevertheless, some practitioners have assumed that the underlying theory and numerical methods are much further advanced beyond the research, development and testing stages than they actually are". In spite of these caveats, the standard advection-dispersion equation can be applied to practical engineering problems provided checks and balances are made. Central to successful predictions, however is a *calibration* of the contaminant transport through tracer and other field data.

3.1.1 Role of Models

Accepted geological engineering practice dictates that any groundwater modeling proceed through the four step process of calibration, verification, prediction and sensitivity (Freeze and Cherry, 1979). However, it is more difficult to calibrate a mass transport code than a groundwater code, even when tracer and other experimental data are available. This is because the groundwater flow aspects must also be calibrated and any uncertainty in groundwater flows translates into uncertainty in mass transport.

Faced with uncertainties in either groundwater flow or contaminant transport many investigators have utilized Monte-Carlo techniques to incorporate uncertainties in all of the various parameters (see Woodbury et al., 1995, for example). This level of sophistication may not be warranted in every case but certainly a sensitivity study is most appropriate when evaluating the results of a contaminant transport exercise.

There is a major difference between evaluating existing sites and evaluating new or planned sites. Schwartz (1990) states "....... recent surveys have shown that there are actually few documented cases where solute transport models have been successfully applied to groundwater field problems involving chemical reactions. In spite of the above limitations, the true value of modeling lies in its capability to integrate site specific data with equations that describe physical processes. Mathematical models are a good aid in understanding sensitivity and when to increase exploration efforts to reduce uncertainty ". One can also upgrade the model as new data becomes available.

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3.2 Relevant Processes

The relevant physical processes of concern are advection, dispersion, sorption and decay. These items will be discussed in turn and related to the parameters chosen.

3.2.1 Dispersion

A major focus of research efforts over the last 10 years has been on the nature of dispersion and whether the contaminant equation really represents the process causing changes in concentration. Bear (1979) and other basic works postulate that the dispersive process is Fickian in nature, i.e. the dispersion process is one in which the concentration gradient is the driving force for dispersive flux. This assumption incorrectly represents the actual physical process that cause dispersion at the scale of many field problems (Schwartz, 1990). It is now well accepted that dispersion is actually related to the spatial variation in hydraulic conductivity. Neglecting or ignoring the true spatial velocity distribution must be compensated by a model with a corresponding high degree of dispersivity.

For a homogeneous, isotropic aquifer two constants α_L and α_T control the dispersive terms in the equation. Most simulations adopt this formulation even when the aquifer is anisotropic with respect to flow. If one uses single values of α_L and α_T in a simulation involving anisotropic media, the dispersive fluxes will be overestimated and underestimated at different parts of the media (Schwartz, 1990). This could conceivably lead to significant errors in predicting concentration. In this work a simple anisotropic dispersion model was chosen that allows for separate dispersivity in each of the coordinate directions α_x, α_y and α_z. The values for α_x, etc. are taken from standard sources (Gelhar, 1986). Note that transient groundwater flow fields represented by a mean steady-state flow system (as done at Rainy Hollow) ignore the temporal variation in groundwater flow and must be compensated by an increased value of transverse dispersion α_y. Without recording hydrographs, one can only estimate a reasonable value based on the observed spreading of DDT. This issue will be discussed later in this report.

3.2.2 Advective Transport and Retardation

These processes control the amount of mass moved by flowing groundwater. Schwartz (1990) states "In the field the single most important key to understanding mass transport is an accurate descrip-

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tion of the flow system. Most transport models include reaction terms that are mathematically simple such as decay and retardation. These do not represent the true complexities of many reactions. Adsorption of cations is an example of this phenomena. Equilibrium (batch) tests show that in the laboratory cations can attach to charged surfaces, particularly clays. If one increases the concentration of the solute, more material adsorbs to the clay. Empirical fits to the data often show a linear trend, the slope of which is K_d the distribution coefficient". Therefore it is easy to include this type of reaction as linear and reversible in the standard transport equation. The coefficient of retardation is linked to K_d by

$$R = 1 + \frac{\rho_b K_d}{n}$$

This equation may not be valid for fractured media and Freeze and Cherry (1979, p 410) discuss this issue in some length.

Many researchers note that reaction processes in general may not be reversible or linear. According to Vick (1990) the distribution coefficient approach is subject to the following limitations:

1. The concentrations of the solute must be small since ion exchange mechanisms have limited capacities to remove contaminants,

2. The flow must not be concentrated within geologic discontinuities. Fractured media causes channeling of seepage, does not provide as much surface area for reaction than material tested in the laboratory and would result in an overestimate of contaminant removal.

An estimate of the groundwater velocity based on the mean value of a statistical evaluation of K and gradients approximated from the various plots indicates:

$$v = \frac{K}{n_e}\frac{dh}{dl}$$

$$v = 2.6 \times 10^{-6} \times 0.075/0.27 \times 86400 \times 365 = 22 \text{ m/yr}$$

Retardation is important in that the velocity of the contaminants is retarded with respect to groundwater flow by the relationship:

$$v_c = \frac{v_w}{R}$$

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Therefore the higher the retardation coefficient the slower the contaminant actually moves. Generally when K_d values are greater than 10, solutes are usually considered immobile (Freeze and Cherry, 1979). The K_d distribution coefficient for sorption of DDT given by

$$K_d = f_{oc} K_{oc}$$

The values of K_d are linked by the organic carbon fraction in the aquifer and the value of $\log(K_{oc})$ is 5.77. The former f_{oc} values are not known with certainty. Based on an assumed literature-value of 0.0009 for the fraction of organic carbon, a value of R is computed to be 3,526. This would suggest that the DDT should essentially be immobile; however, this is not supported by the field evidence of an observed plume of DDT arriving at the outflow face (Klehini River) after about 20 years. This further suggests that the available organic carbon material content in the aquifer material is low and the value of contaminant velocity can only be estimated by calibration to the observed DDT plume.

3.2.3 Decay and Decay Chains

One aspect of the contaminant transport problem that is greatly simplified in this analysis is the degradation of DDT. DDT does degrade by hydrolysis and oxidation to first DDD and then DDE (Fetter, 1993). In order to simulate a decay chain, separate mass transport equations for each component need to be solved with each component species having several sources and sinks related to mass creation and decay. This level of sophistication is not judged to be warranted at this time. Therefore, an approximate technique was used in which the contaminant transport was assumed to be represented by the sum of all the DDT isomers and a single first order decay parameter λ was chosen. Typical decay rates noted in the literature (Spitz and Moreno, 1996) suggest a half-life of 16 days to 31 years for the degradation of DDT in soils. Having no other information a value of 15 years was chosen for the base case parameter set.

3.2.4 Boundary and Initial Conditions

In order to obtain a solution to the advection dispersion equation it is necessary to apply initial and boundary conditions. The initial conditions describe the value of the variable under consideration (concentration) at some initial time. The boundary conditions specify the interaction between the

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area under investigation and its external environment. Boundary conditions are of three types, fixed concentration, specified flux and mixed. Fixed concentration boundaries typically apply to contaminant sources that are maintained at a fixed concentration for the duration of the simulation. If the concentration is known or estimated, this condition is appropriate. The second type or specified flux condition equally could apply if this quantity was known on the sides or top of a geologic layer in which no-flow of contaminants is specified. The third type or mixed condition applies when an aquifer is in contact with a stream or lake of known or unknown concentration. Generally it is more difficult to conceptualize boundary conditions in contaminant transport and these must be chosen correctly for quantities such as mass flux to be calculated correctly.

For the simulation is this work, a constant concentration boundary condition was chosen to represent the source. The source concentration was assumed to be 3,400 ng/L which is the solid-solubility value for DDT in water. There has been some questions raised about the solubility of DDT in the presence of hydrocarbons at the site and indeed, DDT is typically dissolved in diesel fuel for ease of application. A DDT/diesel combination trapped in residual saturation levels probably represents the source material at Rainy Hollow. It is possible that locally, the water-solubility of the DDT/diesel mixture may be higher that 3,400 ng/L. However, away from the NAPL source DDT would most likely precipitate into solid form as fresh water moves that material away from the source and therefore dissolution is limited by DDTs solid-solubility (Pankow and Cherry, 1996).

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4.0 Contaminant Transport Model and Solution

4.1 Analytic Model

The chosen conceptual model for DDT transport is represented by a patch source, 30 m by 2 m deep with a fixed concentration of 3,400 ng/L. The groundwater flow is assumed steady and uniform. Retardation (solid-phase surface reactions) is described by a linear equilibrium isotherm and biochemical decay by a first order constant (see Domenico and Schwartz, 1990 for more details). The Klehini River forms a boundary at a fixed distance from the source. In this proposed model however, this boundary is ignored. It is important to note that the *computer model is not intended to replicate all of the features observed in the field but to capture primary effects and to aid in understanding.* Used in this way the model serves as an educational tool to provide insight into the mechanics of the system so that sound engineering decisions can be made.

The governing equation for the chosen conceptual model allows for three dimensional dispersion, but groundwater flow is uniform and steady in one direction only. This assumption simplifies the resulting mathematics considerably. The equation to be solved is

$$D_{xx}\frac{\partial^2 C}{\partial x^2} + D_{yy}\frac{\partial^2 C}{\partial y^2} + D_{zz}\frac{\partial^2 C}{\partial z^2} + V_x\frac{\partial C}{\partial x} - R\lambda C = R\frac{\partial C}{\partial t} \tag{4.1}$$

In the above the D_{xx} etc., represents the coefficient of hydrodynamic dispersion (L^2/T) which is equal to $D_{xx} = \alpha_x V_x$, and $D_{yy} = \alpha_y V_x$, with $D_{zz} = \alpha_z V_x$. R is the retardation coefficient which is equal to V_x/V_c, V_c being the velocity of the contaminant (L/T). λ is a first order decay constant $1/T$ equal to 0.693 over the half-life of decay. C is the concentration of the contaminant M/L^3 and t is the time. The boundary conditions are (a) the concentration remains fixed for all time

$$C(0, -Y/2 \leq y \leq Y/2, -Z/2 \leq z \leq Z/2, t) = C_0$$

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and (b),

$$\frac{\partial C(\infty, y, z)}{\partial x} = 0$$

The initial conditions are $C(x, y, z, 0) = 0$. The solution to the above is [Domenico (1987)]:

$$\begin{aligned} C(x,y,z,t) &= (\frac{C_0}{8}) \exp \left\{ \left(\frac{x}{2\alpha_x} \right) \left[1 - \left(1 + \frac{4\lambda\alpha_x}{v_c} \right)^2 \right] \right\} \\ & \text{erfc} \left[\frac{x - v_c t (1 + 4\lambda_x / v_c)^{1/2}}{2(\alpha_x v_c t)^{1/2}} \right] \\ & \left\{ \text{erf} \left[\frac{y + Y/2}{2(\alpha_y x)^{1/2}} \right] - \text{erf} \left[\frac{y - Y/2}{2(\alpha_y x)^{1/2}} \right] \right\} \\ & \left\{ \text{erf} \left[\frac{z + Z/2}{2(\alpha_z x)^{1/2}} \right] - \text{erf} \left[\frac{z - Z/2}{2(\alpha_z x)^{1/2}} \right] \right\} \end{aligned} \quad (4.2)$$

4.2 Computer Simulations

4.2.1 Calibration and Verification

The base calibration runs consist of solving (4.2) and adjusting input parameters until a reasonable match is achieved between the observed range in total DDT isomers in water measured in the mini-piezometers MP96-01, 02, and 03. Table 1 below lists the final 'best' values for the parameters.

Table 1 Base Case Parameters

Parameter	Value
Source Concentration (ng/L)	3,400
Source Width (m)	30
Source Thickness (m)	2
DDT velocity (m/yr)	2.0
DDT half-life (yr)	15.0
α_x (m)	10.0
α_y (m)	5.0
α_z (m)	1.0
Distance to point (m)	80.
Evaluation time (yr)	20

Calibration targets were set at the mini piezometers (1 - 8 ng/L). The predicted concentration based on the above parameter set is 7.08 ng/L after 20 years duration. This value is within the calibration 'window' of 1 to 8 ng/L. Verification targets were also set at WP7 and WP13. At these locations, 400 and 200 ng/L concentrations were measured in 1996, respectively. The above

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computer model predicts 171 ng/L and 532 ng/L at these locations and therefore generally confirms the validity of the computer model. Based on these results, it seems reasonable to conclude that our conceptual model adequately represents the physical processes taking place at the site.

4.2.2 Sensitivity

The sensitivity runs consist of increasing the base-case values noted above one-at-a-time by 20% while holding the other values constant at their base values.

Table 2 below lists the adjusted values and the corresponding increase in predicted concentration at 80 m distance.

Table 2 Sensitivity

Parameter	Value	Percent Change
Source Concentration (ng/L)	4,080	20
DDT velocity (m/yr)	2.2	45
DDT half-life (yr)	18.0	12
α_x (m)	12.0	29
α_y (m)	6.0	8

As Table (2) indicates above the concentrations are moderately sensitive to the source concentration. The DDT velocity and the dispersivity produced the highest changes in concentration; as might be expected.

4.2.3 Simulations

Figure 1 shows a contour map of DDT concentration in an aquifer after 20 years of release. The contour interval on the plot is 10 ng/L. The left-most concentrations are not plotted due to the high density of contour lines and steep gradients. The right side of the plot represents the outflow face, similar to the boundary of the Klehini River. This plot indicates that most of the mass of the DDT is distributed close to the source; a likely consequence of slow groundwater movement and mass loss due to degradation. Recall that the travel time to the outflow face (defined as the time at which one-half of the source concentration value arrives at the outflow face) is about 40 years, almost 3 half-lives of decay. Most of the mass of the plume is within about 40 m of the source. The next graph, Figure 2 shows a temporal plot of DDT arrival at the outflow face with time. Note that the concentration of DDT is predicted to rise steeply until about 50 years when it is expected to level off. It is important to note that this model assumes that the source itself does not decay.

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5.0 Future Modeling and Monitoring Program

5.1 Proposed Numerical Model

As mentioned, the original focus of the investigative studies was to determine if concentrations at the outflow face (Klehini River) are likely to increase with time. It was concluded that the conceptual model chosen for this task adequately reflects the hydrogeology of the site. In order to incorporate new information (in terms of long-term modeling) and to make more precise predictions about future behavior, the analytic model that was used in this phase of the study will need to be replaced with a more sophisticated model.

It is proposed that a two-dimensional finite-element mathematical model be used to simulate groundwater flow and contaminant transport at the site. Later a procedure for incorporation modeling results and updating predictions will be described.

It is unlikely that a three-dimensional model is needed at this site. Instead, it is proposed that a *hydraulic approach* (Bear, 1979) be used; that is, a two-dimensional plan-view of the aquifer. In this idealization all flow is assumed to be horizontal and as a result such a model would predict vertically average quantities, such as concentration. The 2-D approach is valid if the slope on the water table is small. Note that the current hydraulic gradients are about 4%; therefore this assumption is reasonable.

The finite element method is proposed to solve the mathematical boundary value problem. This technique is well developed and accepted, and has the necessary flexibility in terms of capturing complex boundary geometries. The writer has written various programs that are suitable for this purpose and possesses preprocessors and mesh generators.

It is the intention of the writer to investigate whether or not one can reasonably decouple the flow

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and mass transport equations. Ideally, it would be advantageous if the site had the characteristics of steady groundwater flow field. However, this behavior will have to be assessed from analysis of the water levels measurements that will be made at the site.

5.2 Methodology

The following list describes the topics and a brief description of each topic that will be included with future modeling efforts. This list will include a description of the computer programs chosen, the results of their application and the degree of success in accomplishing our objectives. Specifically,

5.2.1 Computer Code

This section will describe why the computer code was developed. There are a variety of codes to simulate the simultaneous movement of water and chemical species under transient stresses. The vast majority of the easily obtainable codes require that the groundwater velocities be at equilibrium. For the Rainy Hollow site equilibrium behavior may not be attained due to (possibly) high seasonal recharge events. It was considered more appropriate to continue with two-dimensional (areal) models since these are simpler and more practical to use, and are more consistent with the available data. The consultant also has obtained a suitable finite element grid generator (GRID-BUILDER) for this purpose.

The final model shall include such effects as steady or transient flow, decay chain mass-transport, retardation, dispersion and advection.

5.2.2 Relationship Between Conceptual and Mathematical Models

This section will describe how the conceptual model of the aquifer was translated to the grid of the mathematical model. It will describe how space and time were discretized, how the model boundaries were defined, how the model was zoned into a series of homogeneous domains, and how parameter values were assigned to the each zone in the grid. The method and rationale used to assign initial parameter values and stresses to each cell or node will be discussed. Aquifer thicknesses and elevations will be determined from previous reports. The report may also include a discussion of the uncertainly in model parameters and stresses, and a statement of the range of values that are accepted as valid during calibration. It may also indicate if some of the parameters or stresses are known with such a low degree of certainty that they are estimated solely by model calibration.

5.2.3 Model Calibration and Verification

This section will describe the calibration process and the calibration targets for hydraulic heads and/or concentrations should be defined and justified. Sources and magnitudes of errors associated with each calibration value will be described. A list of final parameter values and stresses for the final model will be presented along with the simulated water balances. For the transient verification phase, the match between field and simulated heads and flows will be presented with much the same format used to describe the calibration results. Discrepancies between the observed and calculated heads will be discussed.

5.2.4 Sensitivity Analysis

This analysis recognizes that the calibrated model most likely will not represent a unique match to the calibration target. This section documents the sensitivity of the results to variations in parameter values, grid size, boundary conditions, and calibration criteria. A justification of the scope of the sensitivity analysis and a set of figures and/or tables showing the results of the analysis will be given.

5.2.5 Predictions

Here the parameters determined through calibration and verification are used to predict the response of the system to future events. An important task is to determine the length of time for which the model will accurately predict the future. A "rule of thumb" is that a predictive simulation should not be extended into the future more than twice the period of which verification data are available, but this rule may not be possible if longer simulations are required. It is considered that predictions for a 10 - 50 year period are desirable. Two major pitfalls in predictions are uncertainly in the calibrated model and uncertainly about future hydrological stresses. Each of these requires another sensitivity test. Furthermore, many predictive simulations require estimates

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about the likelihood and magnitude of future hydrological or human-regulated events. Because such information may be at best, known on an ad-hoc basis, new errors are introduced into the simulation. Therefore, it is critical that multiple scenarios are used and presented in this section.

5.2.6 Model Limitations

This final section will state the limitations of our study, such as two-dimensional approximation, fixed river heads, etc. The appropriate use of the model results will be discussed. For example, has the model been verified and deemed accurate enough so that the model can be used for management decisions?

5.2.7 Incorporation of Monitoring

A logical procedure for incorporating measurements and conditioning models based on these data is called *Bayesian Updating*. The procedure is well established (see Woodbury, 1988). In this approach *a priori* values of parameters (for instance hydraulic conductivity) are assumed on subjective grounds or by analysis of a data base from a geologically similar area. As measurements become available during site investigations 'updated' estimates of these parameters are generated. The updated estimates can be used as input variables in further conditional simulations such as stochastic pore-pressure or contaminant transport modeling. Massmann and Freeze (1987) applied such a methodology as a form of conditional simulation to quantify whether hydraulic conductivity measurements are cost-effective in reducing risk for owner/operators of landfill sites. Hachich and Vanmarcke (1983) applied Bayesian updating techniques in the interpolation of hydraulic head fields. Their algorithm first used an a priori hydraulic conductivity distribution to generate a mean hydraulic head field and covariance by a first-order second-moment method. Second, they updated this prior hydraulic head field with measurement values using the Bayesian procedure.

5.3 Monitoring Schedule and Parameters

5.3.1 Water Levels

Water levels are to be measured at three locations on the lower bench area. These are 96-19A, 96-22 and 96-18. Please refer to the attached drawing for locations and other pertinent details.

Monitoring in 96-19A will be carried out with a continuous recorder and 96-18 and 96-22 on a twice per-month frequency from May to October in 1997, 1998 and 1999.

5.3.2 Contaminants

It is proposed that the specific parameters electrical conductivity (TDS determination), temperature, and pH be determined directly in the field and water samples will be taken for DDT and isomers as well as BTEX. The points selected will sample shallow and deep horizons as well as background levels. The points are WP-7, WP-13, 96-21 (a, b), 96-17 (a, b), MP-1, MP-2, MP-3 and 96-18 (background). These points are to be sampled on an annual basis for five years in July of each year. A duplicate sample will be taken from MP-2 to check on the precision of the laboratory results.

5.3.3 Surface Water

Referring to map 3.5 from '1996 Detailed Site Investigation Report', it is proposed that three points in the Klehini River at 96-01. 96-02 and 96-04. Parameters DDT and isomers and BTEX are to be sampled on an annual basis (July of each year).

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6.0 Conclusions

The original focus of the investigative studies was to determine if concentrations at the outflow face (Klehini River) are likely to increase with time. In order to deal with this issue an appropriate *conceptual model* of the site needed to be developed. This report expands on the conceptual model of the DDT transport at the Rainy Hollow site previously developed (RRU, 1997) and evaluates the validity of that model with a mathematical solution to the appropriate boundary value problem. The additional analyses and documentation is intended to provide reviewers with more details on the proposed model and evaluates the likely accuracy of predictions of DDT fluxes to the Klehini River.

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Table 1 in the text lists the final 'best' values for the parameters. Calibration targets were set at the mini piezometers (1 - 8 ng/L). The predicted concentration based on the above parameter set is 7.08 ng/L after 20 years duration. This value is within the calibration 'window' of 1 to 8 ng/L. Verification targets were also set at WP7 and WP13. At these locations, 400 and 200 ng/L concentrations were measured in 1996, respectively. The above computer model predicts 171 ng/L and 532 ng/L at these locations and therefore generally confirms the validity of the computer model. Based on these results, it seems reasonable to conclude that the conceptual model adequately represents the physical processes taking place at the site.

Figure 1 shows a contour map of DDT concentration in an aquifer after 20 years of release. This plot indicates that most of the mass of the DDT is distributed close to the source; a likely consequence of slow groundwater movement and mass loss due to degradation. The concentration

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of DDT is predicted to rise steeply until about 50 years when it is expected to level off.

This report also contains a suggested strategy for future monitoring and modeling efforts and presents a monitoring schedule with lists of parameters to be measured. The modeling and monitoring strategy proposed herein is designed to answer several key questions. One of these questions to be answered after five years or sooner is whether the predictions can confirm that no further action is required, and that the monitoring program can be discontinued. If the converse is true then additional contaminant risk assessment may be needed to determine whether more pro-active remediation is warranted.

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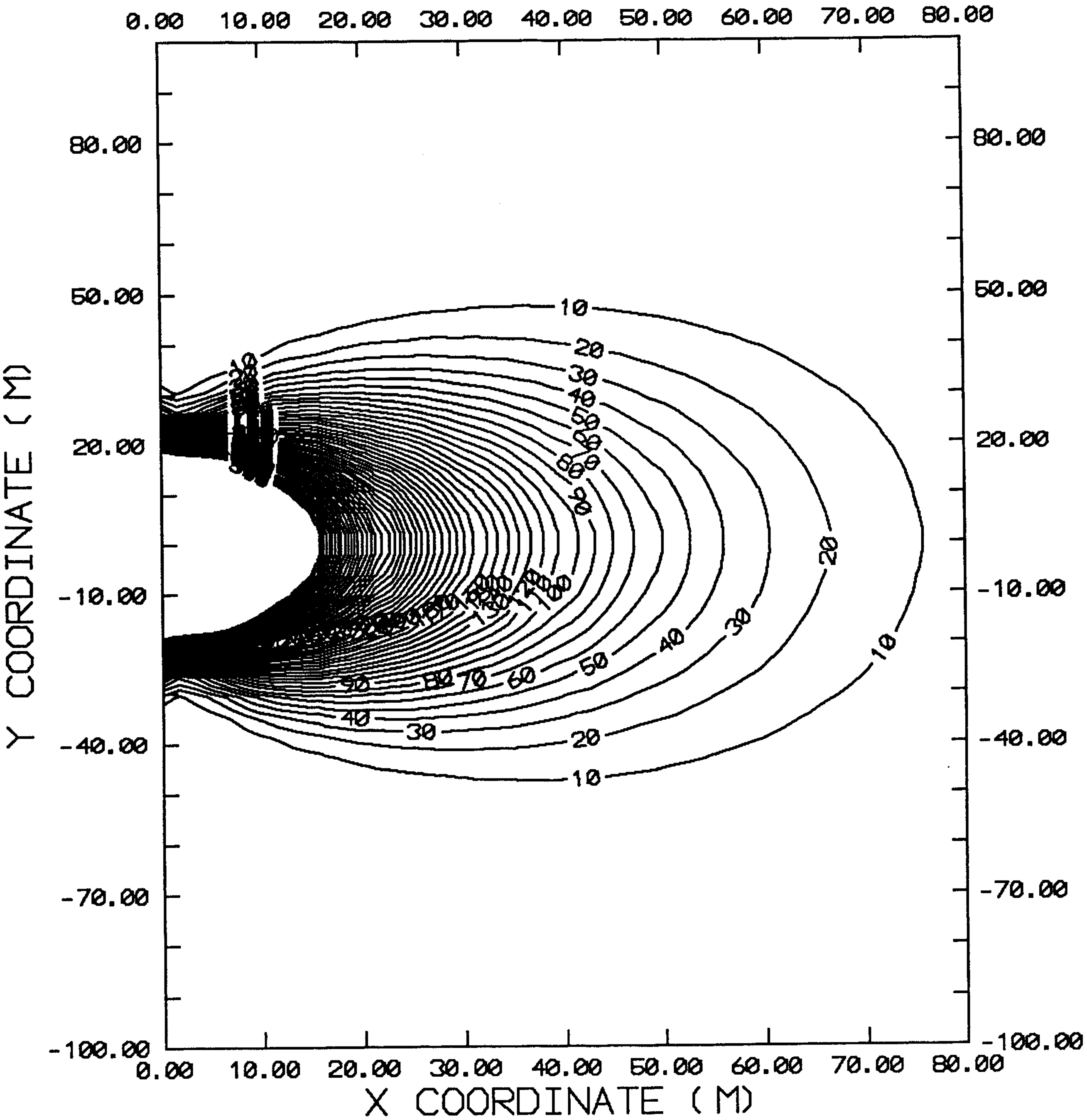
Woodbury, A.D., 1988. Bayesian updating revisited, *Math Geol*, **21(3)**, 285-308.

DRAFT



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UMA Engineering Ltd.
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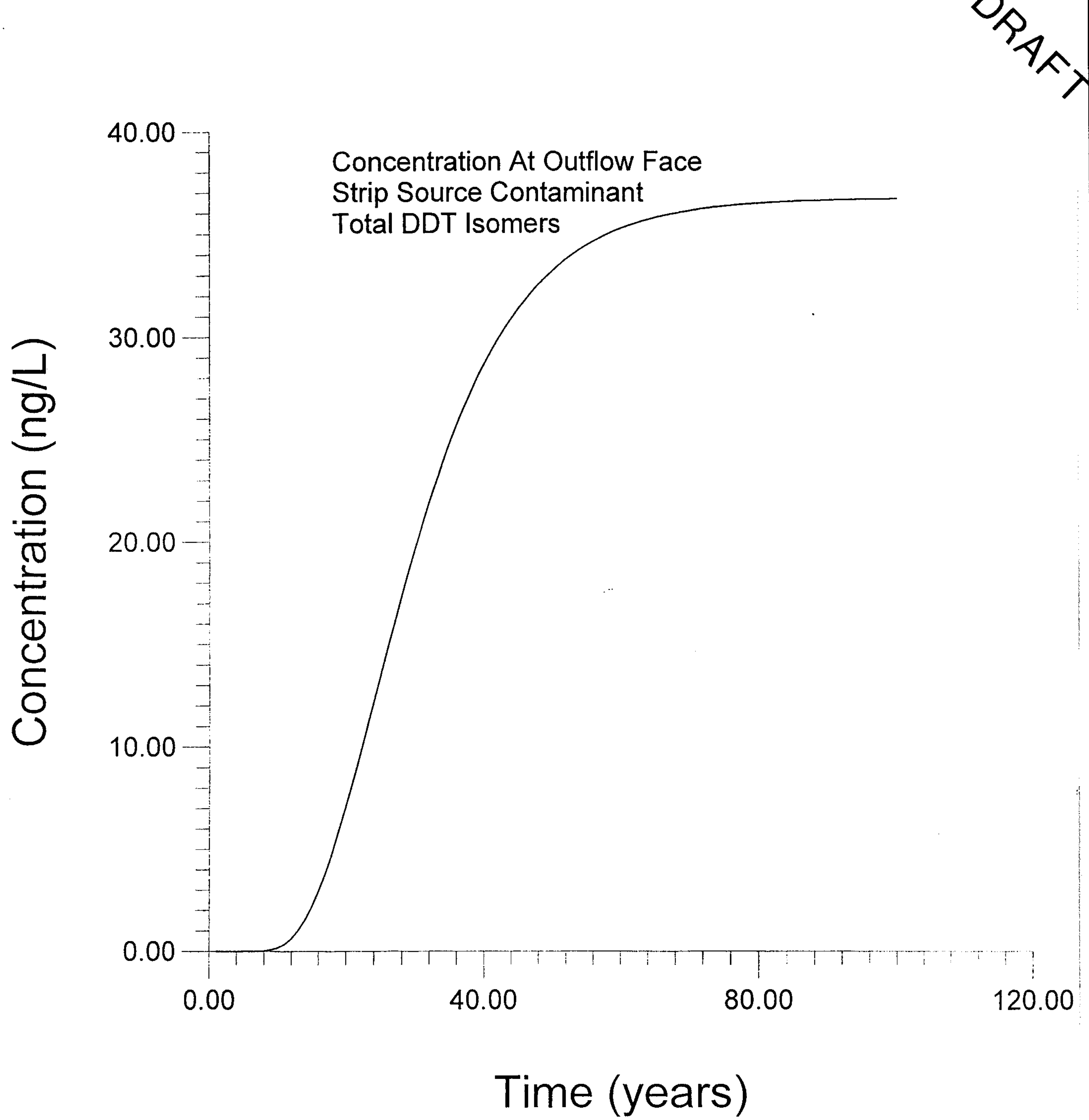
1479 Buffalo Place, Winnipeg, Manitoba, Canada R3T 1L7

Indian and Northern Affairs Canada
Waste Management Yukon

TITLE:	RAINY HOLLOW SIMULATED TOTAL DDT (20 YEARS)		
JOB No.	C799-001-01-02	DATE:	AUGUST 1997
DRAWN:	DML	FIG. No.	1
CHECKED:	TW		



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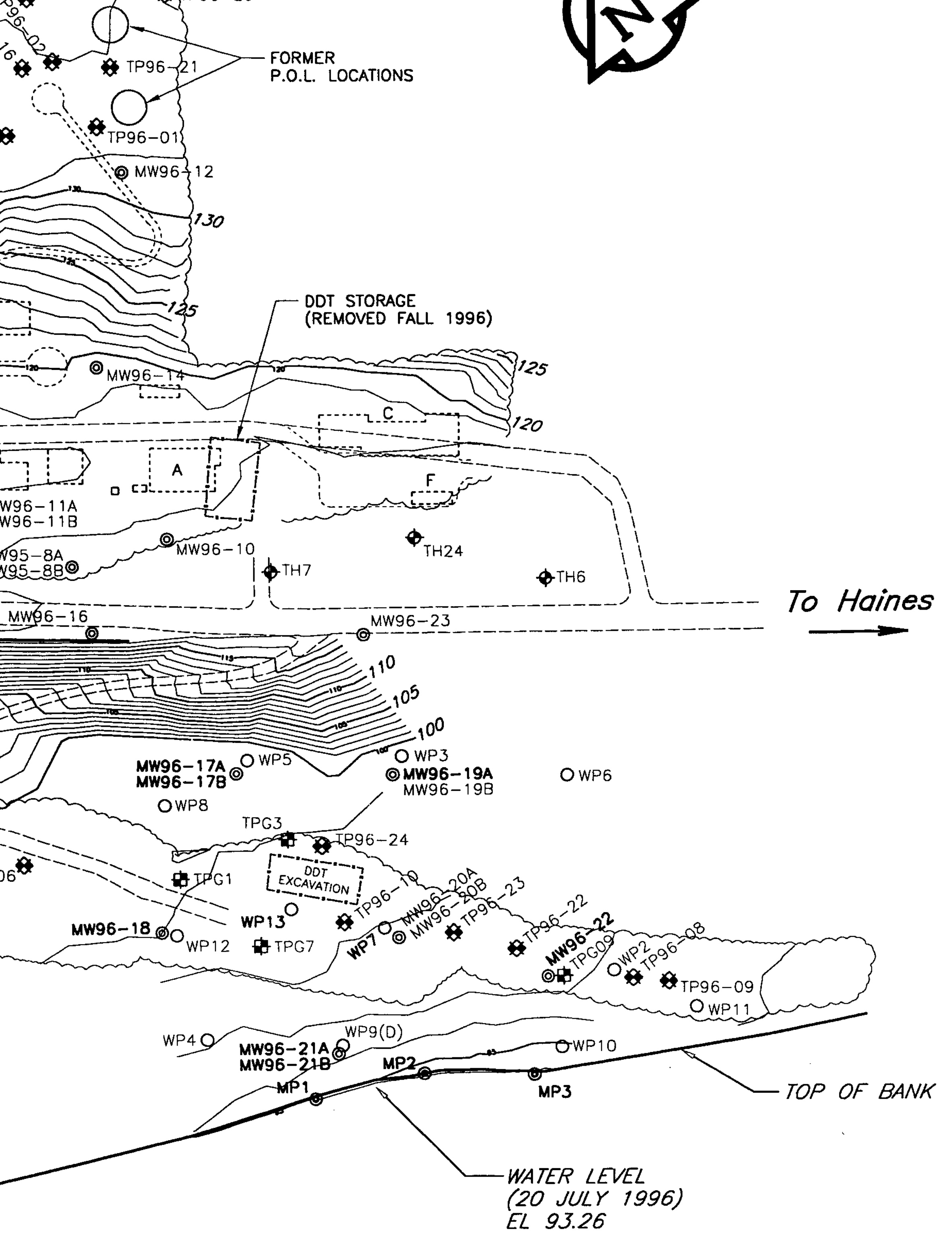
TITLE:	RAINY HOLLOW DDT CONCENTRATION AT OUTFLOW FACE		
JOB No.	C799-001-01-02	DATE:	AUGUST 1997
DRAWN:	DML	FIG. No.	2
CHECKED:	TW		



◎	MONITORING WELL (UMA 1995, 1996)
◉	MINI PIEZOMETER (UMA 1996)
○	WELL POINT (Golder Associates 1994)
✚	TEST PIT (Golder Associates 1994)
✤	TEST PIT (UMA 1996)
(D)	DESTROYED
———	EDGE OF ROAD
- - - -	FORMER EDGE OF ROAD
～～～	TREE LINE
～	ELEVATION CONTOUR
- - ->	CREEK
A	APPROX. LOCATION OF FORMER BUILDINGS

A – MAIN LINE PUMP BUILDING
B – UTILITY BUILDING
C – WAREHOUSE/SHOP/GARAGE
D – APARTMENT COMPLEX
E – DORMITORY
F – PUMP ISLAND

WATER LEVEL MONITORING LOCATIONS

96–18, 96–22 – TWICE PER MONTH (MAY to OCTOBER)

96–19a – CONTINUOUS WITH DATA LOGGER (MAY to OCTOBER)

ANNUAL GROUND WATER SAMPLING LOCATIONS

WP–7, WP–13, 96–21 (a & b), 96–17 (a & b), MP–1, MP–2, MP–3, 96–18 (Background)

ANNUAL SURFACE WATER SAMPLING

Annual re–sampling and analysis of sites;
Kle 96–01, 96–02 and 96–04
(See map 3.5 from '1996 Detailed Site Investigation Report')

Scale 1:2000

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